Edge computing: Architecture, Applications and Future Perspectives

Marieh Talebkhah
Department of Computer and Communication Systems Engineering
Universiti Putra Malaysia
Serdang, 43400, Malaysia
marieh.talebkhah@yahoo.com

Aduwati Sali
Department of Computer and Communication Systems Engineering
Universiti Putra Malaysia
Serdang, 43400, Malaysia
aduwati@upm.edu.my

Mohen Marjani
Faculty of Innovation and Technology
School of Computer Science and Engineering, Taylor University
Selangor, 47500, Malaysia
mohsen.marjani@taylors.edu.my

Meisam Gordan
Department of Civil Engineering
Faculty of Engineering
University of Malaya
Kuala Lumpur, 50603, Malaysia
meisam.gordan@gmail.com

Shaiful Jahari Hashim
Department of Computer and Communication Systems Engineering Universiti Putra Malaysia,
Serdang, 43400, Malaysia
sjh@upm.edu.my

Fakhrul Zaman Rokhani
Department of Computer and Communication Systems Engineering
Universiti Putra Malaysia
Serdang, 43400, Malaysia
fzr@upm.edu.my

***Abstract*— The fast advancements in the fields of mobile internet and the internet of things (IoT) have caused several serious challenges for the traditional centralized cloud computing like large latency, small spectral efficiency (SE), and incompatible machine type of communication. Aimed at resolving the mentioned issues, several innovative technologies have been developed to shift the functions of the centralized cloud computing to the edge device of the network. Various edge computing techniques based on diverse origins have been established to decline the latency while improving SE, and supporting the massive machine-type communications. The present article offers an overview on three edge computing technologies: mobile edge computing, cloudlets, and fog computing. Specifically, standardizing procedures, principle, architecture, and utility of the mentioned technologies will be addressed. In terms of radio access network, the mobile edge computing difference from the fog computing was described. Features of fog computing radio access networks will be addressed as well. In the end, unsolved issues and future research topics will be discussed.**

Keywords*— *Internet of Things (IoT), Mobile Edge Computing (MEC), Fog Computing, Cloudlets, Edge Computing.

I. Introduction

Past decades have witnessed a huge development in cloud computing and its widespread applications which can be assigned to its cost-effectiveness and consolidation-based flexibility, by which computing, storage, and network management will be achieved in a centralized way. The speeding growth of mobile internet and the internet of things (IoT) resulted in serious problems for the currently-available centralized cloud computing architectures. Mobile devices in connection with a faraway centralized cloud server have obtained complex applications, giving rise to additional burden on the radio access network as well as the backhaul network which can lead to great latency. Moreover, by the huge development in the wide diversity of access devices and end user's demand, IoT caused an entire digital revolution in our modern lifestyle. Based on Cisco's estimation, the statistics IoT-connected devices will reach 50 billion by 2020. The development of IoT will result in several issues (e.g. latency, restricted capacities, resource-limited devices, continual services with sporadic connectivity, security) that may not be sufficiently resolved through the centralized cloud computing architectures. Thus an innovative cloud computing approach capable of modifying the mentioned architecture and alleviating the capacity and latency limitations is highly demanded [1].

The IoT's have several features such as an ultra large network of things, device, and network-level heterogeneity, as well as huge number of events produced by them. The mentioned characteristics can challenge the extension of its various applications and services [6]. The accomplishment of such requirements could become even harder for IoT plus Cloud scenarios. IoT applications can result in generation of a huge deal of data through IoT sensor. An analysis is then conducted on these data to identify proper reaction to the events or extract the necessary analysis results. Nonetheless, transmittance of the entire data to the cloud requires an ultrahigh network bandwidth. Recent studies have been devoted to finding a better way for the capabilities exploitation at the network edge for supporting IoTs and their requirements [7].The edge computing involves generation of a huge deal of data using various kinds of IoT devices whose processing could be achieved at the network edge rather than its transmittance to the centralized cloud infrastructures. This approach can resolve the bandwidth and energy issues. In this regard, edge computing can be considered a new paradigm aimed at providing storage and computing resources and serving as the new layer, consisting of edge devices between the end-users of IoT devices and the cloud layers. From the perspective of edge computing, an "edge" is defined as a computing and network resource within the initial source of the data path to the destination data storage (fog nodes, cloud data centers).

Upon convergence with IoT, edge computing could become even stronger and offer innovative methods for the IoT system. Various definitions have been expressed for edge computing; the most relevant one can be found in [2]. Accordingly, edge computing was defined as a paradigm enabling the technologies

978-1-7281-6946-0/20/$31.00 ©2020 IEEE

to allow computing at the network edge, on downstream and upstream data on cloud and IoT services behalf, respectively. This model relies on a novel concept and regarding some similarity in nature, “edge computing” in literature could imply other architectures like Mobile Edge Computing (MEC), cloudlet computing, or fog computing (FC). Nonetheless, edge computing could be recognized as a link bridging IoTs to the nearby physical edge devices for facilitating the use of the newly-emerged IoT applications in the user’s device (e.g. mobile devices) (Fig.1).

Fig.1. Edge computing approach by IoT and edge devices.

As time passed, IoT devices also proliferated and explosively grew by connecting things and operative parts. If such a device attempts loading its entire computations to the cloud, there will be sufficient bandwidth permitting them to continuously communicate with the cloud servers [3]. Moreover, cloud server overloading could be another serious issue. In spite of the cloud structure power, the time-crucial operations could not be properly achieved; moreover, the operations requiring excellent internet connectivity will be disturbed. This specifically holds for time-crucial situations like telemedicine and patient care, in which a millisecond disturbance could result in non-compensable outcomes.

The edge computation has gained increasing popularity in both industry and academic communities as it can effectively offer massive machine-type communication with extremely small latency and superior spectral efficiency (SE). To meet the low-latency requirement in the case of resource-intensive applications, a novel architecture component (known as cloudlets) was proposed [1]. For acceleration of the ecosystem development on the basis of cloudlets, Vodafone, Intel, and Huawei companies in partnership with Carnegie Mellon University (CMU) established the open edge computing (OEC) initiatives in June 2015.

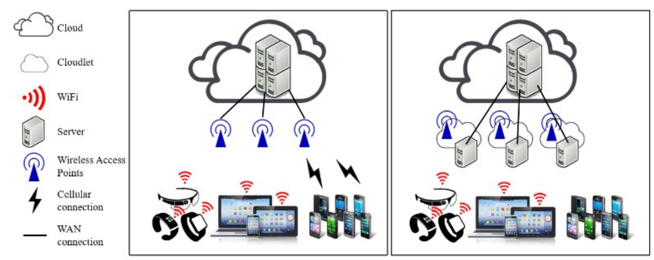
The following items will be covered in the rest of the present article: cloudlets principles and applications will be investigated in Section II; while the mobile edge computing standardization, applications, and architecture will be addressed in Section III. Section IV is a brief description of standardizing procedure, utilities, architectural aspects of fog computing as well as its comparison with MEC in terms of radio access networks (Fog-RANs). The unsolved problems and challenges will be discussed in Section V. Finally, Section VI will provide a conclusion for the discussions.

II. CLOUDLET

Also known as micro cloud data centers, cloudlets operate similarly to the small cloud computing architectures inherited from the centralized Cloud Computing (CC) [2]. Cloudlets are concentrated on serving time-critical applications under limited bandwidth conditions. Regarding the mobile code offload [4] and cost declining architecture of the centralized clouds [5], cloudlets structures sound highly crucial. This can conditionally justify the differences of the enterprise from the cloud service data centers.

The cloudlets are mainly aimed to support interactive mobile applications with huge resource requirements and provide strong computing resources for mobile devices at decreased latency. The user equipment (UEs) could reach the computing resource of the cloudlet in proximity by the single-hop high-speed wireless local networks. According to Fig. 2, the cloudlets can be regarded as the mid-tier of a 3-tier hierarchical structure (mobile device, cloudlet, and cloud layers) for reaching the crisp response time.

A cloudlet-based open ecosystem can support and enable diverse interesting compute-intensive and latency-sensitive mobile applications. As a instance, through supporting small end-to-end latency, we can implement real-time interactions in wearable cognitive assistance [6]. Exploiting real-time data analyses in internet edge, cloudlets are capable of reducing the input bandwidth of the cloud [7]. Cloudlets can serve as spatially-near substitutes of the cloud which might not be in hand as a result of failure or cyberattacks; thus, cloudlets are able to enhance robustness and availability under hostile environments. Empirical results indicated 51% and up to 42% decline in the response time and energy consumption in a mobile device upon using cloudlets rather than cloud offload [5].



(a) Mobile device-Cloud Architecture
(b) Mobile device-Cloudlet-Cloud Architecture

Fig. 2. Mobile Cloud Computing Scheme.

As decentralized and distributed Internet infrastructures, cloudlets can offer their compute cycles and storage resources to the mobile devices in their vicinity. A Cloudlet is a nearly fixed cloud composed of one or multiple resource-rich, multi-core, Gigabit Ethernet-connected computers capable of supporting nearby mobile devices and lowering the security issues, offload distances, and communicational latency as much as possible. Cloudlets and clouds are compared in Table I.

Contrary to the Cloud, a Cloudlet is situated near the mobile device (often at a one-hop distance) and could be accessed through high-speed wireless links (e.g. Wi-Fi). Cloudlet is known as a “data center in a box” as well; since it is a self-handled, resource-rich system with high-speed access to the real cloud. From the architectural point of view, a Cloudlet encompasses one or several systems with high-speed internal connectivities and leverageable computing resources. Within the framework of the Mobile Cloud Computing model, a Cloudlet-based approach presents several superiorities over the cloud-based approaches (Fig. 3).

TABLE I. COMPARISON OF CLOUD COMPUTING AND CLOUDLET

Characteristics	Cloud	Cloudlet
Computing power	High	Moderate
Resource flexibility	High	High
User acceptance	Acceptable QoE	Excellent QoE
Accessibility	High	High
Client mobility	High	Limited
Cost	High	Low-free
Latency	High	Low
Data security	High	Intermittent
Management	Centralized – complicated	Non-centralized – self-managed
Offline availability	Unavailable	Available
Bandwidth	Low	High
Storage capacity	Pay-as-you-go	High
WAN requirement	Persistent connection	None
State	Hard & soft state	Soft state
Network resource allocation	Large of users (1000s)	A few users (10s)
Deployment environment	Large data centers, controlled environments	Capable virtual deployment at any place
Disaster impact	Catastrophic	Lowest influence

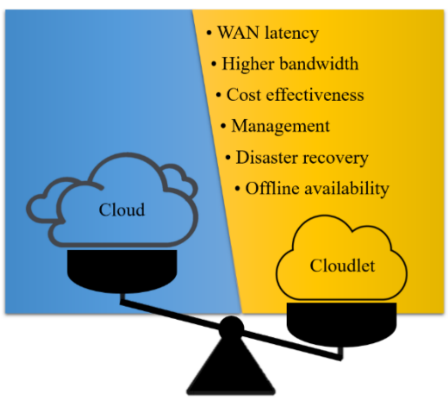


Fig. 3.Cloud Vs. Cloudlet.

III. MOBILE EDGE COMPUTING IN INTERNET OF THINGS

MEC has enabled technologies to offer various CC computational functionalities to Quality of Service (QoS) at the edge of the available networks. MEC offers the possibility of computation at the edge. For instance, micro cloud nodes can serve as an edge node linking mobile devices to the cloud. Gateways the edge devices could connect home IoT to cloud; while a smartphone can be regarded as an edge device linking body things to the cloud [6]. MEC is mainly situated in the mobile network base station [8] it may be occasionally called mobile cloud computing (MCC) [3]. Within the MCC structure, data storage, as well as data processing, is handled outside the mobile device. The logic behind the edge computing concept lies in the preference of deploying the computational facilities in the vicinity of the data generation site. We believe that mobile edge computing could be substituted by fog networking [8], however, mobile edge computing particularly focuses on aspect of things, while fog computing mainly concentrates on the infrastructural aspects. Moreover, fog computing has an improved configuration concerning the edge computing issues. Edge computing is capable of directly driving the intelligence computing, communication capabilities, and processing power of an edge gateway or applications like programmable automation controller [4].

Despite the empowerment of the mobile device computing ability, memory, and other configuration components, these devices still fail to suffice the compute-intensive operations. The mentioned shortcoming has motivated the researchers to develop MCC architecture [9]. By offloading the tasks to the Internet cloud using an MCC network of mobile operators, mobile devices can exploit the strong computing resources and storage capacity of the cloud to carry out the intended tasks. As an evolved form of MCC, MEC was first introduced in 2014 by the European Telecommunications Standards Institute. MEC managed to dramatically decrement the process duration and energy requirements of mobile devices through the deployment of computing resources, network controlling, and cached data in the vicinity of Small-cell Base Station (SBS) and Macro-cell Base Station (MBS) [10]. Regarding restricted computational ability of the mobile device, the vehicle or user are allowed offloading a computation-intensive task to the network edge access points, (e.g. base stations and wireless access points in the MEC systems). Furthermore, task processing can be achieved by the edge server giving rise to a significant decrease in the data transmittance duration in comparison with MCC. Additionally, MEC is highly reliable and energy-efficient and benefits from close range and ultra-low latency. On the other hand, MEC has been recognized as a key 5G technology with diverse applications, as illustrated in Fig. 4 [11].

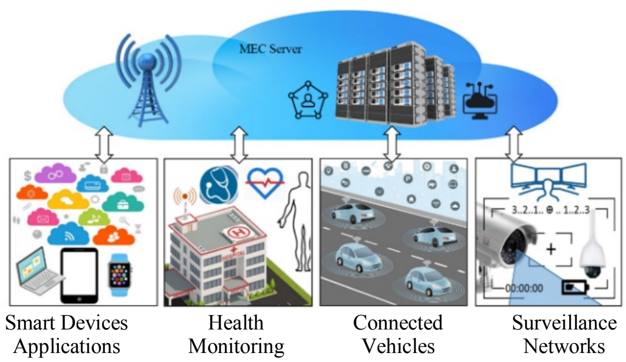


Fig. 4. The architecture of MEC.

According to Table II, MEC and MCC systems are significantly different regarding computing server, end-user distance, and latency. MEC outperformed MCC due to its smaller latency and higher energy efficiency in mobile devices, context-aware computing support, and more secured privacy.

IV. FOG COMPUTING

Fog computing refers to horizontal, system-level architectures capable of distributing computation, storage, control, and networking functions nearby the user in a cloud-to-thing continuum. It is thus serving as a link bridging the cloud and things. It also plays a decisive role in the identification, integration, management, and utilization of multi-tier computing, communication, and storage resources for various IoT systems.

TABLE II. COMPARISON OF MEC AND MCC SYSTEM

	MEC	MCC
Server hardware	Small-scaled data centers possessing moderate resources	Large-scaled data centers (containing numerous high-capability servers)
Server location	Co-located along with wireless gateways, WiFi routers, and LTE BSs	Installed at especial buildings as big as several football fields
Deployment	Heavily exploited by telecom operators, MEC vendors, enterprises, and home users. Requiring light configurations and planning	Used by IT companies, such as Google and Amazon, at a limited number of sites around the globe. Requiring complicated configurations and planning
Distance to end users	Short (tens to hundreds of meters)	Long (sometimes across-continental)
Backhaul usage	Infrequent use improve congestion	Frequent application probable congestion
System management	Hierarchical (centralized/dispersed)	Centralized
Supportable latency	Below 10 ms	Over 100 ms
Applications	Latency-critical and computation-intensive tasks, such as AR, automatic driving, and interactive online games	Latency-tolerant and computation-intensive application, such as online social networking and mobile commerce/ health/learning

The major motivation underlying the shift from cloud to fog computing is to extend CC properties to the edge level, offering CC service to the fast-growing applications in IoT structures. QoS improvement by presenting lower latency and higher bandwidth, and hence improved navigation services are among the other positive points. The uniqueness of fog computing lies in its hierarchy and parallel processing at the core network edge. It means that the fog computing could be considered the significantly expanded deployments of cloud computing. Fig. 5 illustrates the most prominent properties of fog computing.

Fig. 5. Main features of Fog Computing.

The fog computing framework could be recognized as the extremely virtualized computing infrastructures capable of offering hierarchical computing means through the use of edge server nodes. Such fog nodes are able to organize a broad diversity of applications and services for contents storage and processing in the vicinity of the end-user. In this way, fog computing offers effective approaches to overcome the limitations of the cloud (See Fig. 6).

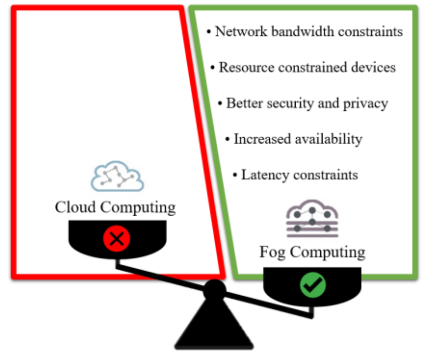


Fig. 6. Cloud Computing Limitation versus Fog Computing advantages.

Based on Fig. 7, fog computing is complementary to cloud computing to augment its reliability and guarantee the QoS at the core network edge. Fog computing could be referred to as an extended cloud service at the IoT devices edge in combat with the drawbacks of conventional cloud computing (CC). The edge nodes sense the raw data and commands as well as controlling the IoT devices.

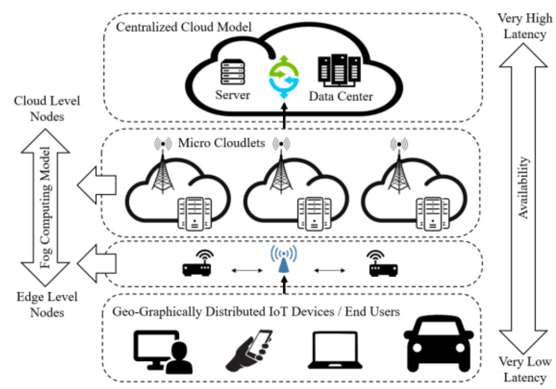


Fig. 7. Fog Computing structure view.

A. Fog Computing Architecture

It encompasses well-distributed heterogeneous devices aimed at deploying IoT applications requiring storage, computational, and network resources dispersed in various geographical sites. Numerous high-level fog architectures were introduced [12], [13] These structures include a 3-layer structure composed of (1) smart devices and sensor layer for data collection and sending to layer-II to be more processed, (2) fog layer which uses computation resources for analysis of the input data and preparing them for entering the cloud layer, and (3) cloud layer capable of large intensive-analysis.

Bonomi et al. [13] introduced a fog software architecture (see Fig. 8) with these main goals:

i) Heterogeneous physical resource. Fog nodes refer to heterogeneous devices that can be exploited on various constituents, including edge router, access point, and high-end server. These components possess various sets of features (i.e. RAM and storage) enabling a new series of functions. This paradigm can be implemented in several OSes and software applications, giving rise to a broad spectrum of hardware and software functionalities.

ii) Fog abstraction layer encompassing several generic application programming interfaces (APIs) offering the opportunity to monitor accessible physically-available resources like CPU, memory, energy, and network. The mentioned layer offers access to the uniform and programmable interfaces to continuously manage and control resources. Moreover, upon the application of the generic APIs, it can support virtualization through monitoring and handling multiple hypervisors and OSes on a single machine to enhance resource utilization. By virtualization, it is possible to have multitenancy through promoting security, privacy to make sure about the separation of various tenants.

iii) Fog service orchestration layer which possesses a distributed functionality and offers an opportunity to dynamically manage the fog service in a policy-based manner. The duty of this layer is to handle various fog node capabilities; hence, a series of novel techniques and components have been developed to assist this procedure. One of the mentioned components is a software agent named foglet which can orchestrate the functionalities through the analysis of the services deployed on the currently-used fog nodes and their physical health. The distributed database (to store policies and resource metadata), the scalable communication bus (for sending control messages to the resource management), and the distribution policy (possessing a one holistic view to applying local alternations to each fog node) are among the other components of this layer.

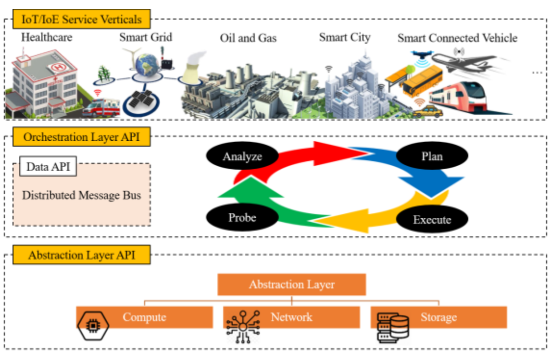


Fig. 8. Fog Computing architecture.

Table III compares the benefits and drawbacks associated with the deployment of fog computing structures.

V. FUTURE CHALLENGES

Through migration of the computation resources to the network edge, fog and edge computing have offered several benefits. The basic idea of these approaches is to establish an IoT network medium under the coverage of a huge amount of interconnected well-dispersed heterogeneous devices for deploying and managing the applications in the vicinity of the user. However, designing such platforms requires meeting all the prerequisites. The present section is thus devoted to the determination and description of the challenges in the path of these paradigms to their full potential. The existing challenges can be classified into three groups: resource management, security and privacy, and network management.

TABLE III. ADVANTAGES AND DRAWBACKS OF FOG COMPUTING

Pros	Cons
System response time improvement	Trust and authentication anxiety
System response time improvement	Wan security concerns
Systematic mobility support	Security issues such as man in the middle and IP address bluffing
Minimization of the core network latency	Accessibility or cost of fog facilities/hardware
Superfluous data restriction support to send at cloud	The physical location could be stolen from any data benefit of the cloud regardless of time and place
Security enhancement by keeping data close to the edge	Privacy issues as a result of the distributed processing schemes

A. Resource Management

Fog and edge paradigms are based on transferring the computation resources from the cloud nearer to the end nodes. Thus, the successful implementation of such systems requires new resource management schemes for complete exploitation of the accessible resources and process applications nearby the user. As an IoT device is resource-constrained, the use of resource managing tools at the edge will let the edge node optimize its resource application (e.g. energy-conservative smart device capable of increasing its battery level upon computation offloading to the nearby nodes), alleviate data privacy, and promote the devices collaboration and resources sharing for processing the IoT applications.

B. Security and Privacy

With the adaption of fog and edge computing concepts, more cloud-based applications are shifted to the edge of the network. Upon deployment and connection to IoT devices, we could easily change our house to a more digitalized medium with automatic adaption with our behaviors. Despite its considerable advantages, some privacy and security issues should be addressed. For instance, the attitudes of a family can be easily read through a simple access to the data collected by the corresponding sensor deployed in the house. Thus, data privacy and security have posed serious challenges to the development of edge and fog computing.

C. Network Management

Network management has a pivotal role in both edge and fog paradigms as it facilitates connection among all smart devices at the edge and provides available resources through exploiting a higher number of nodes. As an IoT network include heterogeneous devices (with wide distribution over large areas), connectivity management and maintenance are of high significance. Newly-emerged technologies such as software-defined networks (SDNs) and network function virtualization (NFV) can be considered as possible solutions with a great influence on the network implementation and maintenance to increase the scalability and reduce the cost.

VI. DISCUSSION

Despite the exciting new horizons opened due to the application of edge computing in centralized cloud computing, the establishment of a balance the competing distributed and centralized network architectures needs smart choices. On principle, the network edge components fail in the management of all IoT-generated data; thus the need for data offloading to the cloud centers still remains. Furthermore, the network edge resources (e.g. computing strength, bandwidth, and communication capability) have to be effectively applied to provide service for real-time utilities. Large-scale and latency-resistant tasks can be addressed at cloud centers at high efficiencies whereas the delay-sensitive tasks should be processed at the network edge. Three different edge computing schemes (e.g. fog computing, mobile edge computing, and cloud) have been introduced in the literature which were briefly addressed in the previous sections. A comprehensive comparison was made between these technologies as listed in Table IV.

TABLE IV. A COMPARISON OF THE EDGE COMPUTING PLATFORMS

	Fog Computing	**Mobile Edge Computing**	**Cloudlet Computing**
Node devices	Gateway, Access points, Switches, Routers, Vehicles, ITS smart devices, personal devices	Servers are installed in base stations	Data Center in a box
Node location	End Devices to Cloud	Marco Base stations/Radio Network Controllers	Outdoor/Local installations
Architecture	single or several layers	Single-layer	Single-layer
Software Architecture	Fog Abstraction layer-based	Mobile Orchestrator-based	Cloudlet Agent-based
Flexibility	Large	Small	Small
Computational capacity	Several levels	Large	Large
Context awareness	Moderate	Large	Small
Proximity	Single or Multiple Hops	Single Hop	Single Hop
Access Mechanisms	Mobile Network, Wi-Fi, Bluetooth, IEEE 802.11p (DSRC)	Mobile Networks	Wi-Fi
Supports non-IP based communications	Yes	No	No
Internode communications support	Completely	Partially	Partially
Latency	Small	Moderate	Moderate
Fault tolerance	Large	Small	Small
Cost	Small (uses legacy or commodity devices)	Large (requiring special devices)	Large (requiring special devices)
Deployment	Ad hoc deployment with no or minimal planning	Planned deployment	Planned deployment
Mobility support	High	Moderate	Moderate

VII. CONCLUSION

Non-stop growth of interconnected IoT devices combined with strict requirements of IoT applications has greatly challenged the available cloud computing architectures in terms of network congestion and data privacy. One of the solutions to overcome the mentioned issues could be the migration of some computational resources near the users. Such approaches can enhance cloud efficiency by expanding its computational capability. The mentioned approach has been further developed through the introduction of several paradigms with their insights and a similar objective: higher resources deployment at the network edge. Despite their common visions, some of these paradigms are under the influence of their cases of application. For instance, the MEC paradigm allows constrained devices such as smartphones to offload some of their applications for saving resources. Fog and edge computing have gained the highest in today's research trend.

As a highly potent computational model, edge computing can provide smart cities with prompt computing and storage resources. Although cloud computing was generally applied for providing computation and storage resources, its intrinsic latency has convinced the researchers to shift the computing and storage resources from a centralized and remote approach to the network edge. Furthermore, instant analytic services are the first requirement of real-time smart applications that can be enabled utilizing edge computing. Nonetheless, full edge computing implementation in smart cities requires resolving several serious challenges.

REFERENCES

[1] Y. Ai, M. Peng, and K. Zhang, "Edge Computing Technologies for Internet of Things: A Primer," *Digit. Commun. Networks*, vol. 4, no. 2, pp. 77–86, 2018.

[2] Q.-V. Pham *et al.*, "A Survey of Multi-Access Edge Computing in 5G and Beyond: Fundamentals, Technology Integration, and State-of-the-Art," *arXiv Prepr. arXiv1906.08452.*, 2019.

[3] G. Javadzadeh and A. M. Rahmani, "Fog Computing Applications in Smart Cities: A Systematic Survey," *Wirel. Networks*, vol. 26, no. 2, pp. 1433–1457, 2020.

[4] J. Santos, T. Wauters, B. Volckaert, and F. de Turck, "Fog Computing: Enabling the Management and Orchestration of Smart City Applications in 5G Networks," *Entropy*, vol. 20, no. 1, 2018.

[5] R. Basir *et al.*, "Fog Computing Enabling Industrial Internet of Things: State-of-the-Art and Research Challenges," *Sensors (Switzerland)*, vol. 19, no. 21, pp. 1–38, 2019.

[6] M. R. Anawar, S. Wang, M. Azam Zia, A. K. Jadoon, U. Akram, and S. Raza, "Fog Computing: An Overview of Big IoT Data Analytics," *Wirel. Commun. Mob. Comput.*, 2018.

[7] A. Greenberg, J. Hamilton, D. Maltz, and P. Patel, "The Cost of A Cloud: Research Problems in Data Center Networks," *ACM SIGCOMM Comput. Commun. Rev.*, vol. 39, no. 1, pp. 68–73, 2008.

[8] M. Al-Khafajiy, T. Baker, A. Waraich, D. Al-Jumeily, and A. Hussain, "Iot-Fog Optimal Workload via Fog Offloading," *Proc. - 11th IEEE/ACM Int. Conf. Util. Cloud Comput. Companion, UCC Companion 2018*, pp. 349–352, 2019.

[9] S. F. Abedin, A. K. Bairagi, M. S. Munir, N. H. Tran, and C. S. Hong, "Fog Load Balancing for Massive Machine Type Communications: A Game and Transport Theoretic Approach," *IEEE Access*, vol. 7, pp. 4204–4218, 2019.

[10] C. Zbakh, M., Essaaidi, M., Manneback, P., Rong, "Cloud Computing and Big Data: Technologies, Applications and Security. Springer," 2019.

[11] S. Yang, "A Task Offloading Solution for Internet of Vehicles Using Combination Auction Matching Model Based on Mobile Edge Computing," *IEEE Access*, vol. 8, pp. 53261–53273, 2020.

[12] C. Avasalcai, I. Murturi, and S. Dustdar, "Edge and Fog : A Survey , Use Cases , and Future Challenges," in *Fog Computing: Theory and Practice*, and A. Y. Z. Assad Abbas, Samee U. Khan, Ed. John Wiley & Sons, Inc, 2020, pp. 43–65.

[13] F. Bonomi, R. Milito, P. Natarajan, and J. Zhu, "Fog Computing : A Platform for Internet of Things and Analytics," *Big data internet things A roadmap smart Environ. Springer; Cham*, pp. 169–186, 2014.